SECTION 2: POSSIBLE CLIMATE CHANGE TRENDS IN HONG KONG AND IMPLICATIONS FOR THE SLOPE SAFETY SYSTEM

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FOREWORD

This Report discusses possible climate change trends in Hong Kong, with particular reference to rainfall, and examines what the implications might be in terms of landslide risk and slope safety. The conclusions drawn are based on analyses of Hong Kong climatological parameters since the early 1950s, and the current scientific consensus on future small-scale and large-scale climate change.

The climatological data were supplied by Dr W.L. Chang of the Hong Kong Observatory. Dr Chang also provided many valuable comments on data analysis and the urban heat-island phenomenon. His assistance is gratefully acknowledged. The rainfall analyses were carried out by Mr N.C. Evans of Special Projects Division, who also wrote the Report.

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ABSTRACT

The Slope Safety Technical Review Board recommended in 2000 that GEO examine rainfall data to see whether any possible climate change related trends were visible and, if so, what the implications might be in terms of landslide risk and slope safety.

The current scientific consensus on climate change is that "global warming" is a real phenomenon, and that noticeable regional climate changes in the next 50 to 100 years are probable. In addition, there is an increasing acceptance that development often results in local climate change.

Analysis of 50 years of annual rainfall data from Hong Kong shows that average annual rainfall has increased slightly over this period. However, this increase has not been uniform, and has been concentrated in the central (developed) parts of Hong Kong, particularly the northern parts of Hong Kong Island, Kwai Chung, Tsing Yi, Shatin, Tai Po and Tsuen Wan, where annual increases of several hundred millimetres appear to have occurred.

It seems probable that these changes are related to the development of an 'urban heat-island'. The fifty-year trend in other climatological parameters appears to support this hypothesis.

These apparently local changes might continue together with Hong Kong's on-going development. In addition, it is possible that global climate change in the next 50 to 100 years might be significant enough to have a local impact.

Past records should not be automatically assumed to be a sound basis for predicting future events. It would be prudent to review regularly those rainfall parameters used for slope stability analysis, slope design, landslide risk assessment and landslide emergency preparedness planning.

CONTENTS

1. INTRODUCTION

One of the recommendations coming out of the 2000 SSTRB visit was that GEO should examine rainfall records to see whether any climate-change related trends were visible in Hong Kong, and whether there were implications for landslide risk indicators. This Report summarises the work carried out to date, and reaches some initial conclusions. Background information is presented first to allow the Hong Kong data to be viewed in context.

2. GLOBAL CLIMATE CHANGE

2.1 Intergovernmental Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change (IPCC) is a United Nations body which brings together hundreds of scientists and researchers from many countries. The IPCC has published a number of important documents over the last decade, and has recently released a new series of reports entitled "Climate Change 2001" (IPCC, 2001a & b). Although not all scientists agree with the IPCC, the reports it produces are the closest documents available to a consensus from the world scientific community. The IPCC reports can be viewed at and downloaded from the IPCC web site (www.ipcc.ch/).

The IPCC uses the term 'climate change' to refer to any change in climate over time, whether due to natural variability or as a result of human activity. In the past the term has sometimes been used to refer solely to human-induced changes, and this has caused some confusion. The main conclusions of the latest IPCC reports are summarised below.

2.2 Sources of Global Climate Change

Changes in climate occur as a result of both internal variability within the climate system and external factors (both natural and anthropogenic). The influence of external factors can be broadly compared using the concept of radiative forcing, which is a measure of the influence of the factor on the balance of incoming and outgoing energy in the Earth-atmosphere system. A positive radiative forcing, such as that produced by increasing concentrations of greenhouse gases, tends to warm the surface. A negative radiative forcing, which can arise from an increase in some types of aerosols (microscopic airborne particles) tends to cool the surface.

Positive forcing (warming) factors which are assessed to have affected the climate since AD 1750 include increasing concentrations of the "greenhouse" gases, increases in tropospheric ozone, aviation-induced contrails (very minor) and an increase in solar radiation (natural). Negative forcing (cooling) factors over the same period include increases in stratospheric ozone, increases in aerosols (sulphates, organic carbon and smoke from biomass burning) and changes in reflectance (albedo) due to changes in land-use. Temporary negative forcing (lasting only a few years) results from episodic explosive volcanic activity.

The combined change in radiative forcing of the two major natural factors (solar variation and volcanic aerosols) is estimated to have been negative (i.e. a net cooling effect) for the past two and possibly the past four decades.

2.3 Consensus on Recent Global Climate Change

- The global-average surface temperature increased by about 0.6°C during the 20^{th} century (discounting the effects of localised temperature rises due to urbanisation - the so-called "urban heat island" phenomena, discussed later). This warming has been unusual and is unlikely to be entirely natural in origin.

- It seems likely that the 1990s was the warmest decade, and 1998 the warmest year, in the global instrumental record (since 1861). It also appears likely that the temperature increase in the 20^{th} century has been the largest of any century in the past 1,000 years.

- Global sea-level rose between 0.1 and 0.2 m during the 20^{th} century.

- Natural forcing may have contributed to the observed warming in the first half of the 20^{th} century, but cannot account for the warming observed in the second half. Most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentration.

2.4 Consensus on Future Global Climate Change

- The IPCC has examined 35 different scenarios for future emissions and has run a number of different climate models. The following conclusions relate to the main predicted global effects and those that are potentially of particular significance to Hong Kong.

- Global average surface temperature is projected to increase by between 1.4 and 5.8°C between 1990 and 2100. This rate of warming is probably without precedent in the last 10,000 years.

- Warming in the northern regions of North America, and north and central Asia, is likely to exceed the global average by more than 40%. By contrast, in south and southeast Asia the warming is expected to be less than the global average.

- Global mean sea level is predicted to rise by between 0.09 and 0.88 m between 1990 and 2100.

- On a global scale, more intense precipitation events are very likely over many areas, particularly the mid to high latitudes of the northern hemisphere. It cannot be assumed that future hydrological regimes will be the same as those in the past. However, precipitation is very variable in both time and space, and the main characteristic of the long-term global total record is its marked year-to-year variability. If smaller regions are examined, the year-to-year variability becomes even more pronounced.

- It is likely that Asian summer monsoon precipitation variability will increase, although confidence in this projection is limited by modelling difficulties. Modelling results appear to suggest an increase in runoff in the Hong Kong and

Guangdong area, but models are coarse and the scale of any such increase is uncertain. It is not clear whether any increases in annual rainfall would result from larger or more intense rainstorms, or from a greater number of events, or both.

- Prediction of how climate change might affect the frequency, intensity or tracks of tropical storms is highly uncertain. Current Global Climate Models do not have sufficiently fine spatial resolution to simulate individual storms. Some data suggest that minimum pressures may decrease and windspeeds may increase in tropical storms worldwide, although the projected changes are small compared to past inter-annual variability. With increased ocean temperatures it is almost certain that the moisture-holding capacity of the atmosphere will rise, and this might mean precipitation increases in areas frequented by tropical storms. This could also be relevant to Hong Kong.

- A final conclusion, rather depressing if of somewhat more academic interest, is that global mean surface temperature and sea level will continue to rise for hundreds of years after the levels of greenhouse gas in the atmosphere are stabilised.

3. ANALYSIS OF LOCAL CLIMATE RECORDS

3.1 Rainfall

Annual rainfall isohyets for Hong Kong covering the 49-year period from 1952 to 2000 inclusive have been obtained from the HKO. These maps were compiled using all data available at the time and the judgement of the HKO meteorologists. The area covered comprises the entire land area of Hong Kong, and most of the sea area, with the exception of the westernmost part of Lantau, and the Sharp Peak/Crooked Harbour area in eastern Sai Kung (data not available until the 1960s). The data were digitised using the Lands Department survey grid of approximately 1.2 by 1.4 km rectangles. The data covering the grid square in which the HKO is situated were checked against the actual annual figures at the HKO. Agreement was good, suggesting that the digitisation was accurate.

The average rainfall across Hong Kong in each year was calculated by summing the annual rainfall in all the cells and dividing by the total number of cells (approximately 1,150). Overall, the average rainfall over Hong Kong appears to have increased slightly during this 49-year period (see Figure 1).

When the data are examined cell by cell a more complex picture emerges. Regression and moving-mean analyses carried out for the 49-year period for each cell show that annual rainfall appears to have increased significantly in the central parts of Hong Kong, with increases concentrated on Hong Kong Island, Kowloon, Kwai Chung, Tai Mo Shan, Tai Wai/Shatin and Tai Po. Secondary peaks are seen over SE Hong Kong Island and Po Toi, and in the Tuen Mun area. Rainfall elsewhere appears to have either stayed about the same, or decreased. The precise scale of the changes is a little uncertain - neither regression nor moving-mean analyses give a clear picture. The regression analyses suggest a maximum rise of 700 mm, while the moving mean analyses indicate that this figure might be closer to 400 to 500 mm. The changes deduced from the moving means tend to be perhaps 60-70% of those indicated by the regressions. However, both analyses agree on the direction of change in a given grid square, so there is some confidence in the geographical spread (see Figure 2). Figures 3 and 4 respectively illustrate the situation in grid squares showing a large increase and negligible change.

It must be emphasised that the apparent trends shown in these plots are small compared to the inter-annual variability. Conventional statistical analyses of these data show very high scatter, and measures of significance are not high. This is not unusual when dealing with trends over time in natural systems. The inter-annual variability of precipitation is notoriously large. However, the geographical spread of trend values (Figure 2) does not appear to be random, and might indicate that an underlying mechanism is at work.

3.2 Possible Urban Heat Island Effects

Hong Kong, and the Pearl River Delta region as a whole, has seen tremendous growth in the built environment over the last twenty to thirty years. It is widely recognised that urbanisation and changes in land use can have a marked effect on local climate. This is not a global warming issue, it is more a question of urban areas generating their own microclimates through additional heating. The phenomenon is known as an "urban heat island". The following processes are relevant.

- Cooling from the evaporation of soil and vegetation water does not occur in urbanised areas. Instead, buildings and roads absorb and radiate solar energy.

- Waste heat from buildings and transport can contribute as much as one third of the heat received from solar energy.

- Buildings conduct heat much more efficiently than rural vegetation, and the canyon structures created by tall buildings enhance warming by trapping solar energy via multiple reflections and reducing infrared heat losses by absorption.

The urban heat island may increase cloudiness and precipitation in the city, as thermal circulation sets up with the surrounding region. Strong winds will tend to reduce this effect, so it is not a phenomenon that could be expected to have much impact during a typhoon. However, the heavy rain events which result from intense convective activity associated with low pressure troughs or unstable southerly airflows might perhaps be exacerbated. The effects of triggering or increasing convection in these airflows might not be confined directly to the built-up areas. It is possible to envisage situations in which enhanced convection could move "downstream", or, conversely, could trigger additional convection "upstream".

If Figure 2 is viewed with this in mind, and bearing in mind the dominant southerly airflow during much of the wet season, it is possible to see a consistent pattern in the annual rainfall trends which might perhaps be connected to the generation of a heat island over the major urban and industrial areas. Triggering of convection upstream and downstream from these areas in the dominant southerly airflow could perhaps account for the apparent rainfall increases observed over Tai Mo Shan and SE Hong Kong Island/Po Toi.

The HKO have provided average daily temperature data from the HKO site in

Kowloon and from Waglan Island (approximately 5 km south-east of Cape D'Aguilar of Hong Kong Island, and remote from development) for the 48-year period from 1953 to 2000 inclusive. These data (average daily minima, maxima and means) also appear to reveal some long-term trends.

Daily minima (lowest night-time temperatures) at the HKO appear to have risen significantly during the period, when compared with the data from Waglan (see Figure 5). This would seem to support the theory that urban Hong Kong has developed a heat island. The average daily maxima (maximum day-time temperatures) from the HKO do not show this trend - in fact they show a significant relative decrease when compared to the Waglan data (which show a rise during the period - see Figure 6). This might suggest increasing relative cloudiness over the urban area, which again is a possible symptom of the development of a heat island. The possible implications of the measured rise in daily maxima at Waglan are not clear - this could reflect a genuine regional trend. The average daily mean temperatures also show an increasing trend for the HKO as compared to Waglan (see Figure 7).

The above data are fairly crude and are limited in areal coverage, but they do appear to indicate that there have been measurable changes in relative temperature distribution over the last 50 years, and these are consistent with the generation of an urban heat island.

In addition to temperature data, the HKO have also provided plots of total annual sunshine duration and solar radiation at Kings Park (in the urban area of Tsimshatsui) from the 1950s. These parameters (Figures 8 and 9) show a fairly definite drop in values over the last 40-50 years. This is again consistent with the generation of an urban heat island (decreasing sunshine hours and solar radiation suggesting increasing cloudiness).

4. CONCLUSIONS

It appears that there may have been localised increases in annual rainfall of up to 400-500 mm over the last 50 years. These apparent increases are concentrated in the central parts of Hong Kong. It is not possible to demonstrate whether or not the increases are statistically significant due to the large inter-annual variability in rainfall. This is a common problem worldwide in the analysis of precipitation trends. These changes (if genuine) are very unlikely to be a direct result of global climate change (although this might be having an underlying, subsidiary, effect).

The apparent increase in annual rainfall in the central parts of Hong Kong might be due to a "heat-island" effect. Other parameters (temperature, solar radiation and sunshine hours) display trends over the last 40-50 years which would seem to confirm that urban Hong Kong has indeed developed a heat-island. Whether the apparent rainfall trend will continue is a matter of conjecture. However, it would seem reasonable to assume that areas where development is continuing (or, possibly, where there are going to be significant changes in existing development) might experience changes in annual rainfall. Given the possible contribution to heat-island generation of solar reflection and radiation from bare concrete surfaces, GEO's slope-greening initiatives should be viewed positively.

Global warming impacts in the next 50 to 100 years might be significant. Increases in both total rainfall, number of rainstorms and rainfall intensity are possible in Hong Kong, but there are major uncertainties related to the magnitude of any such increases.

5. RECOMMENDATIONS

Recent work (Evans & Yu, 2000) has shown significant variations in intense rainfall parameters across Hong Kong, using records that date back to the mid-1980s when the automatic raingauge system was first commissioned. It would be advisable to periodically re-examine these data, as changes in rainfall intensity and/or location resulting from local and/or global climate change will affect the calculated results. However, these statistical evaluations are representative only of the period covered by the data, and cannot account for possibly continuing trends. It should not be assumed that past rainfall records are necessarily a sound basis for predicting future extreme events. It might therefore also be prudent to regularly re-examine the rainfall return periods used in landslide risk assessments, slope design/stability analysis and landslide emergency preparedness planning, as an allowance for uncertainty can be introduced in this way.

6. REFERENCES

Evans, N.C. & Yu, Y.F. (2000). Regional Variation in Extreme Rainfall Values. Technical Note TN 5/2000, Geotechnical Engineering Office, Hong Kong SAR Government, 25 p.

IPCC (2001a). Climate Change 2001: Impacts, Adaptation and Vulnerability. Technical Summary. A Report of Working Group II of the Intergovernmental Panel on Climate Change, 73 p.

IPCC (2001b). Climate Change 2001: Impacts, Adaptation and Vulnerability. Summary for Policymakers. A Report of Working Group II of the Intergovernmental Panel on Climate Change, 17 p.

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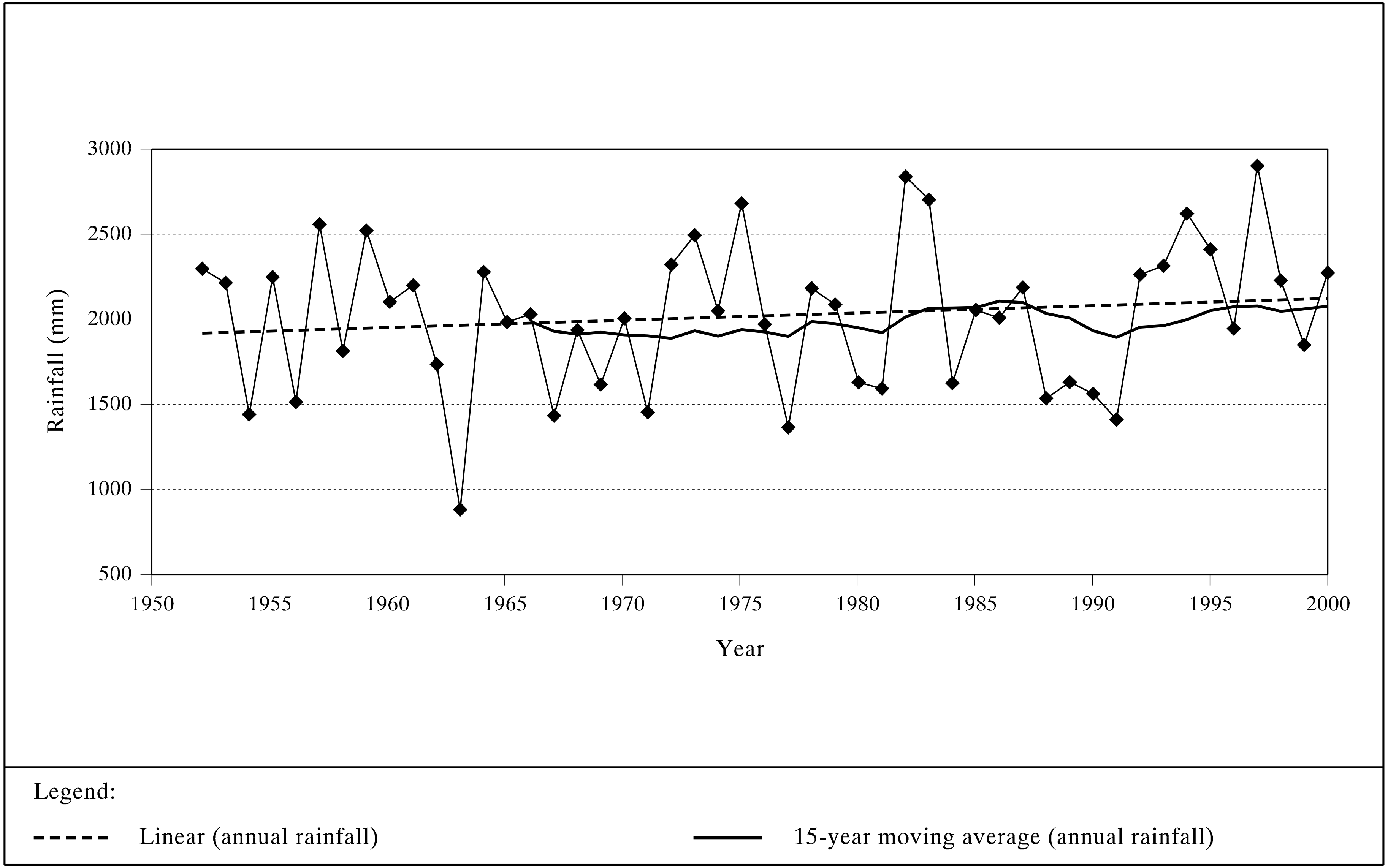
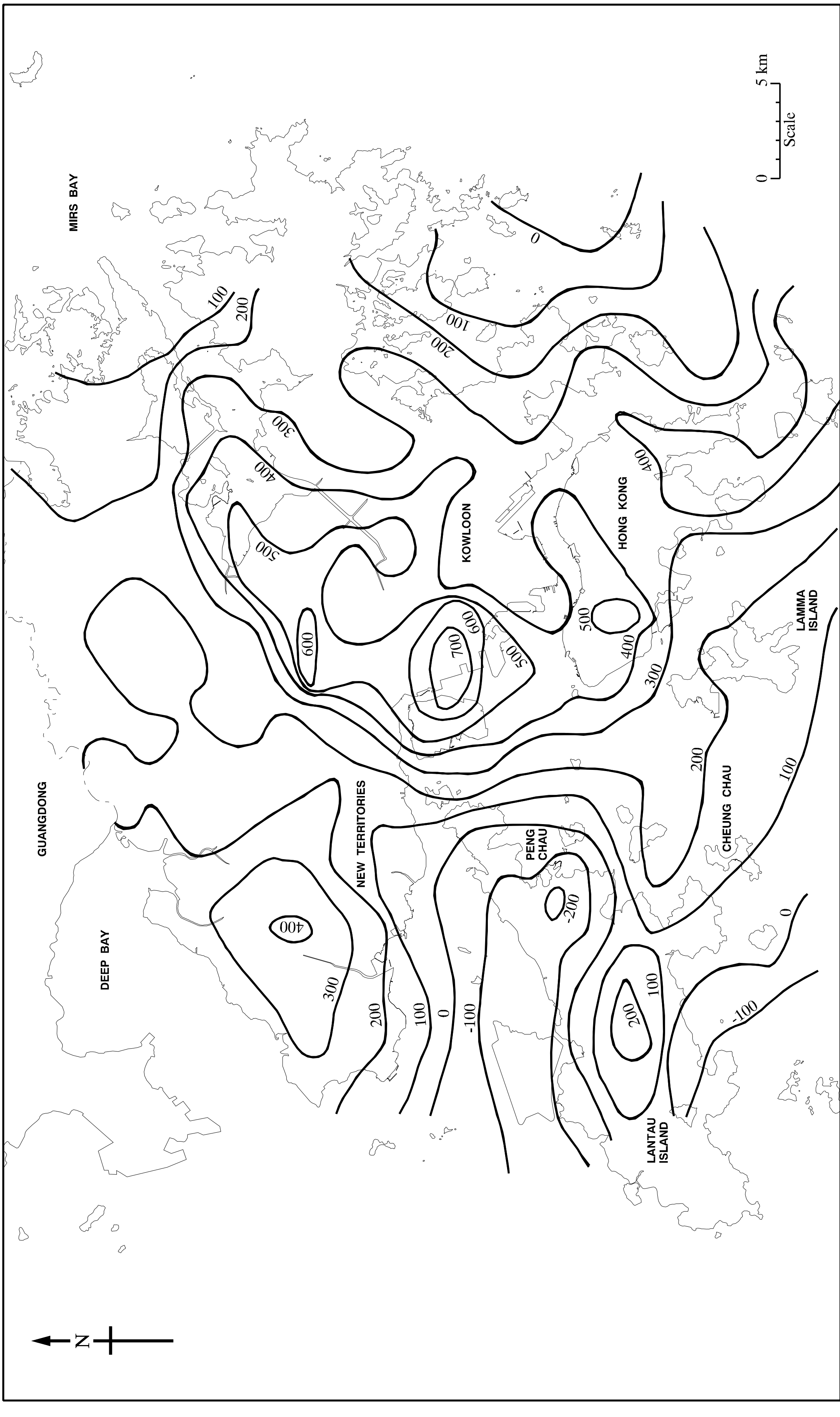


Figure 1 - Areally-averaged Annual Rainfall, 1952-2000



Note: Values in mm derived from regression analyses - moving means indicate values approximately 60-70% of these.

Figure 2 - Possible Change in Annual Rainfall, 1952-2000

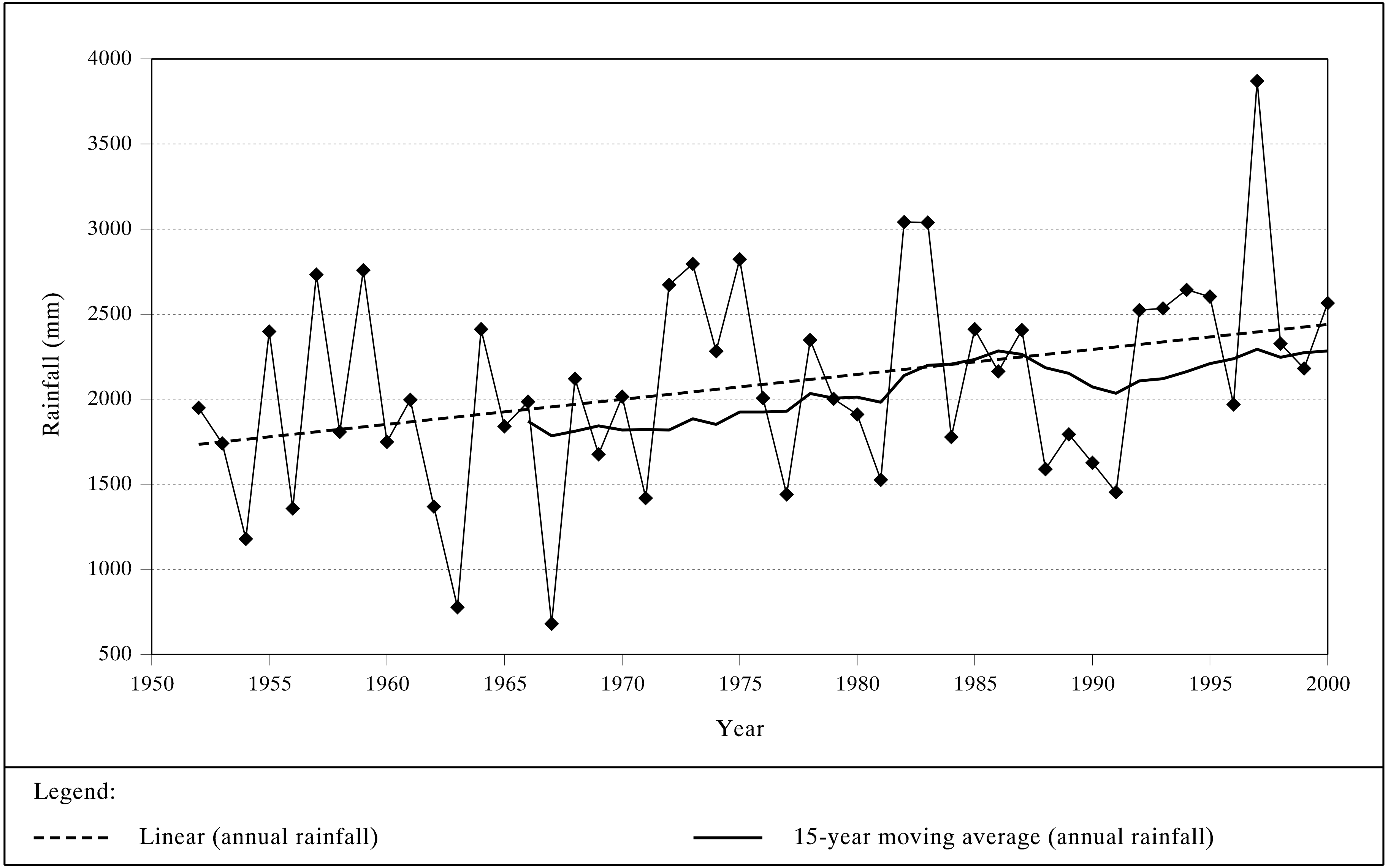
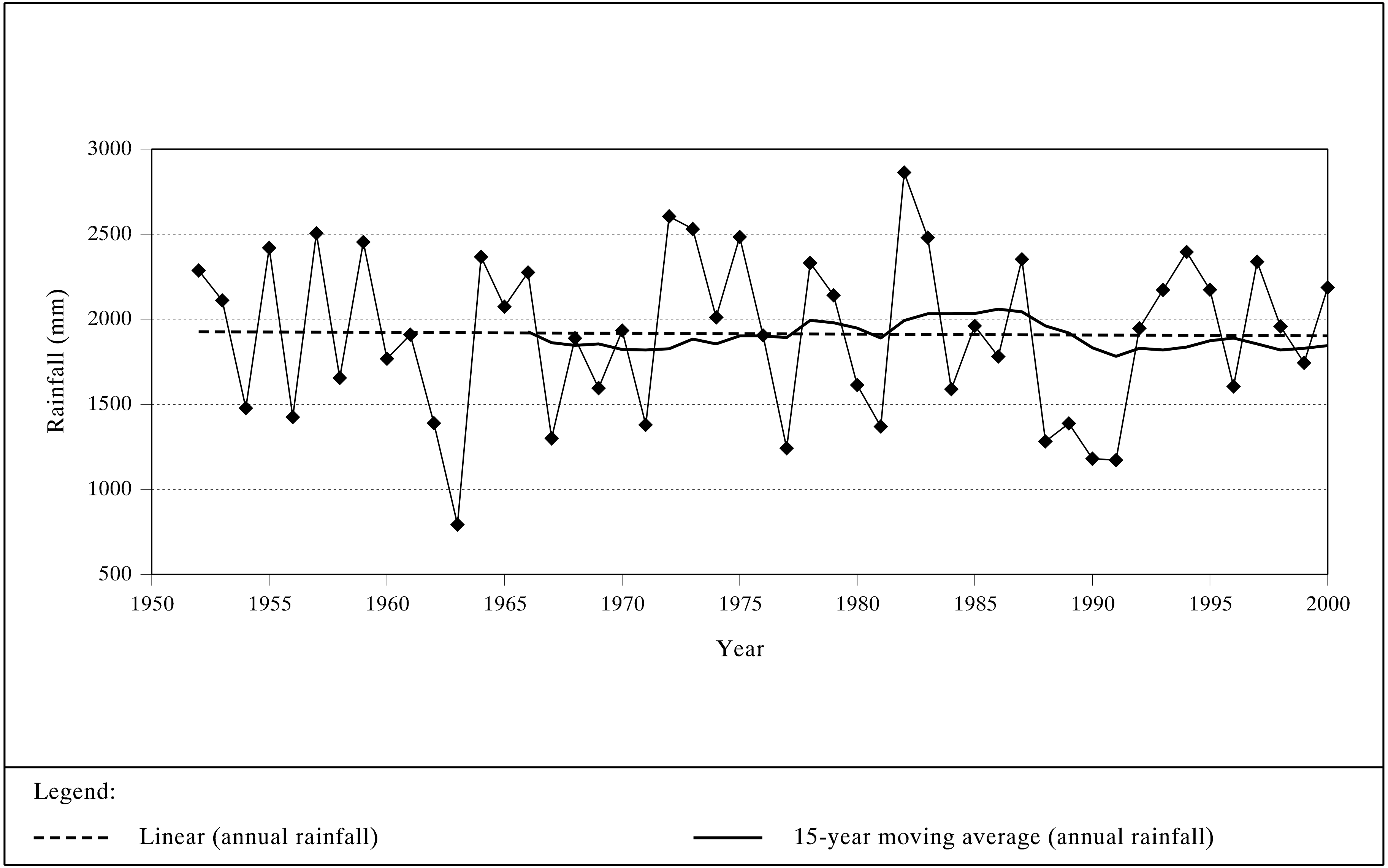


Figure 3 - Example of Large Apparent Rise in Annual Rainfall (11NW-6, Kwai Chung)



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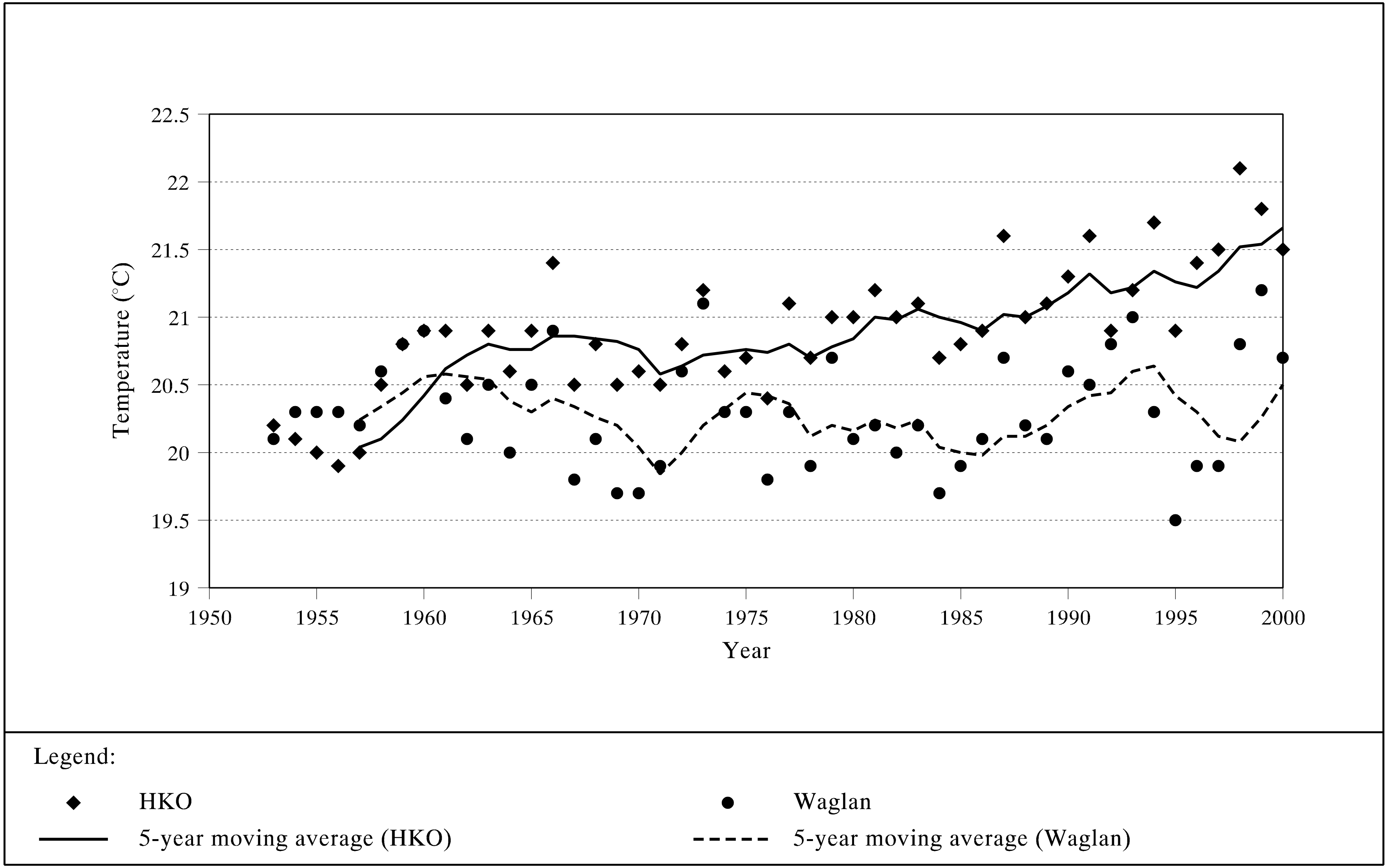
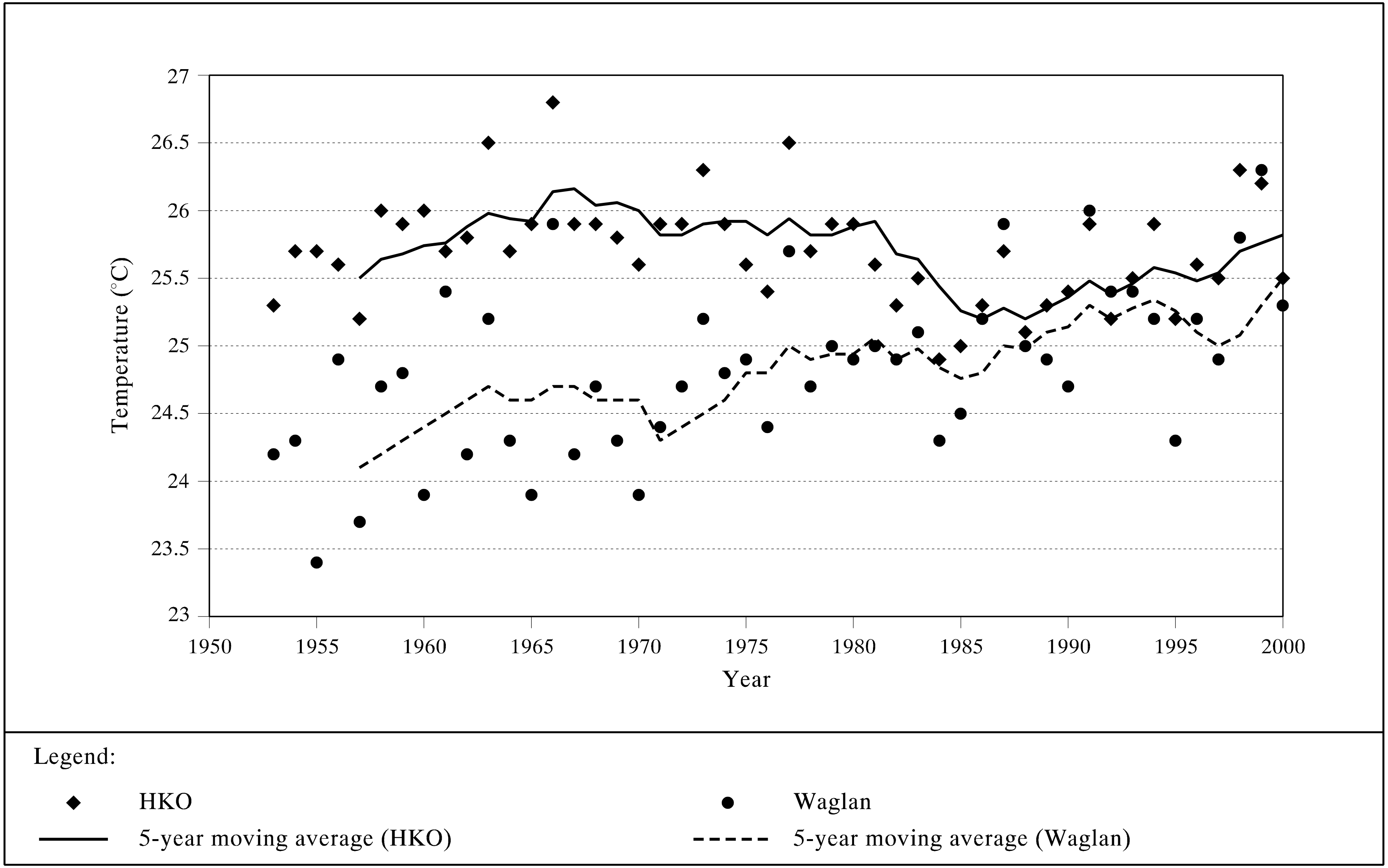


Figure 5 - Average Daily Minimum Temperatures, HKO & Waglan



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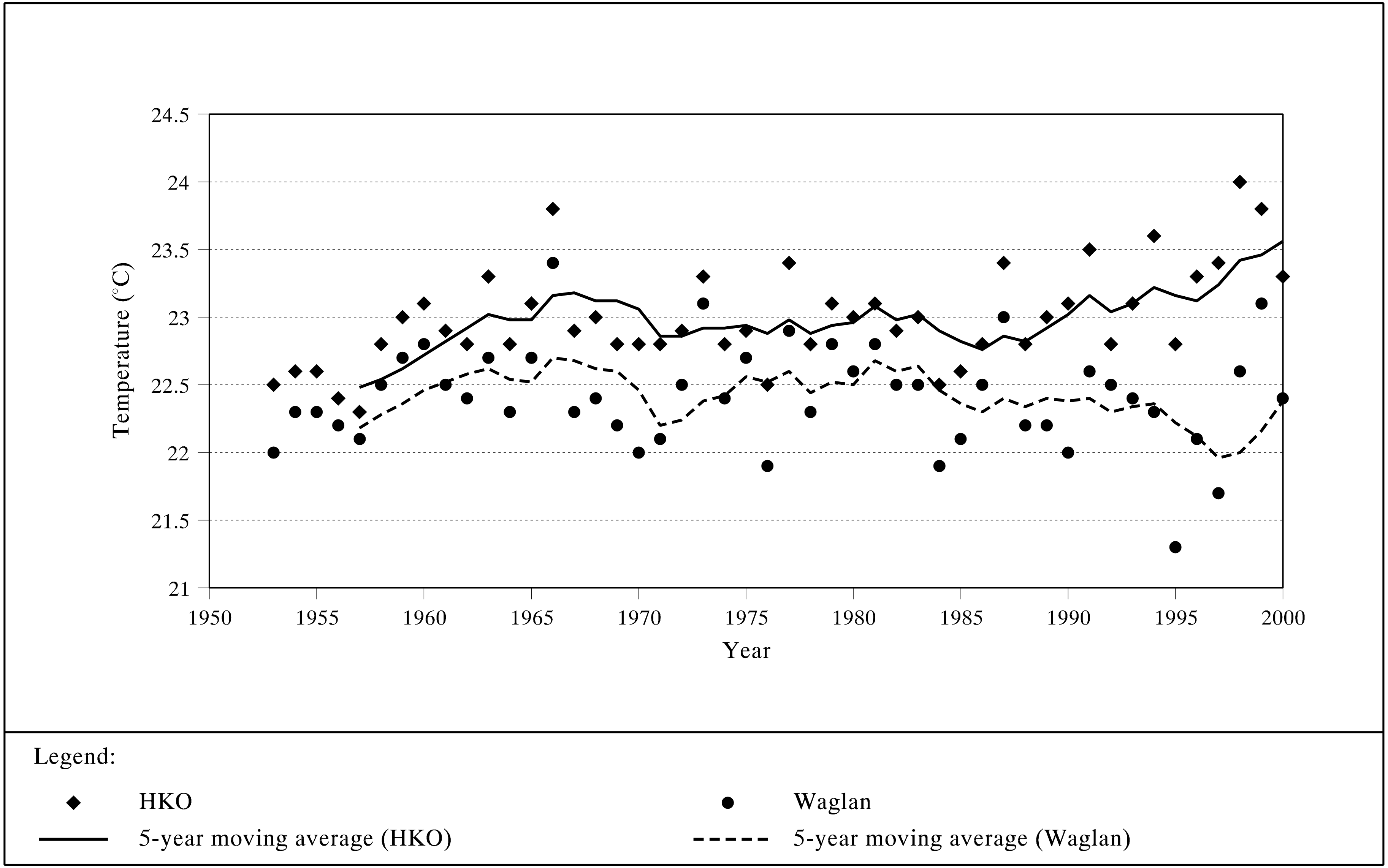

Figure 7 - Average Daily Mean Temperatures, HKO & Waglan

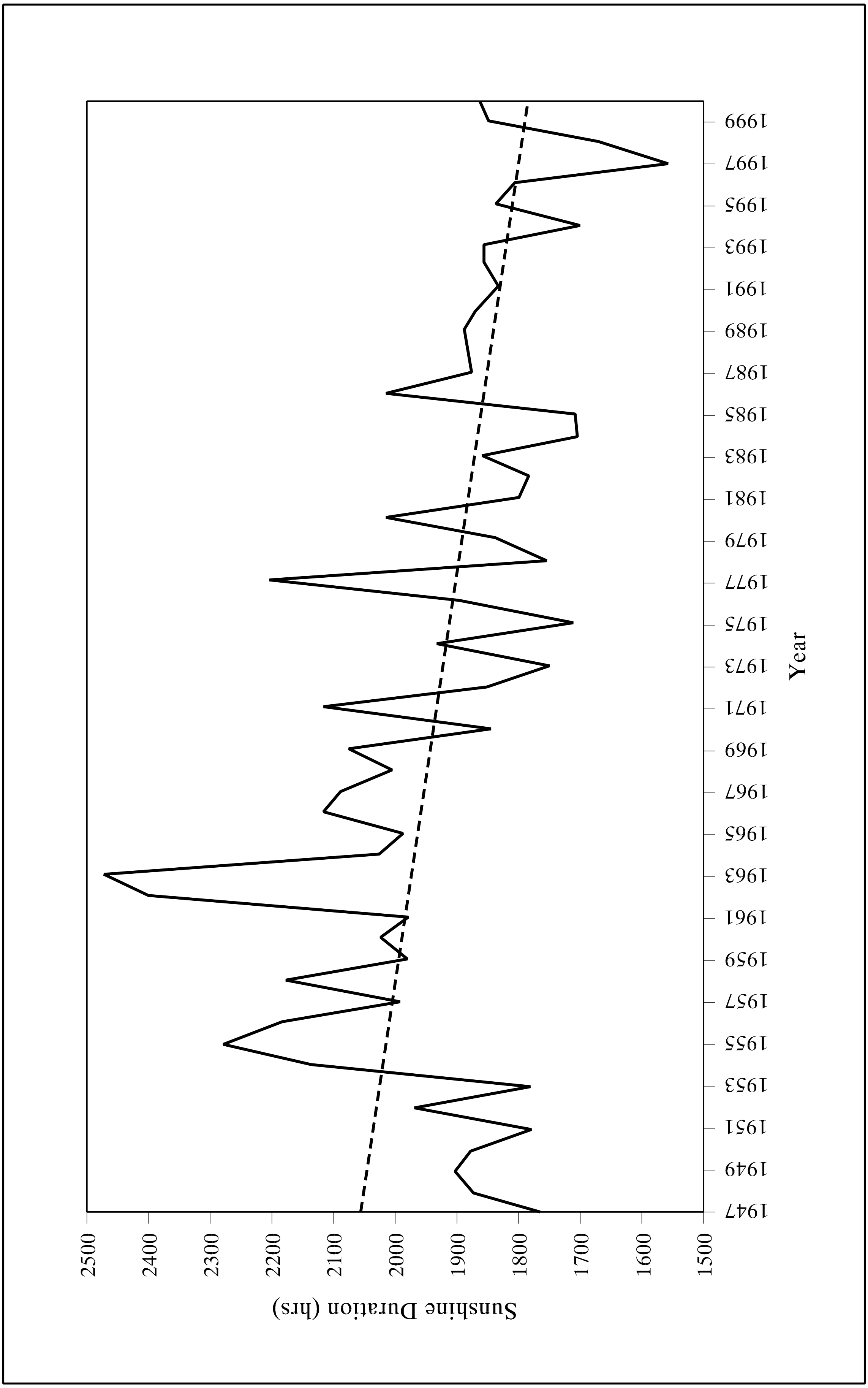

Figure 8 - Sunshine Duration, Kings Park, 1947-2000

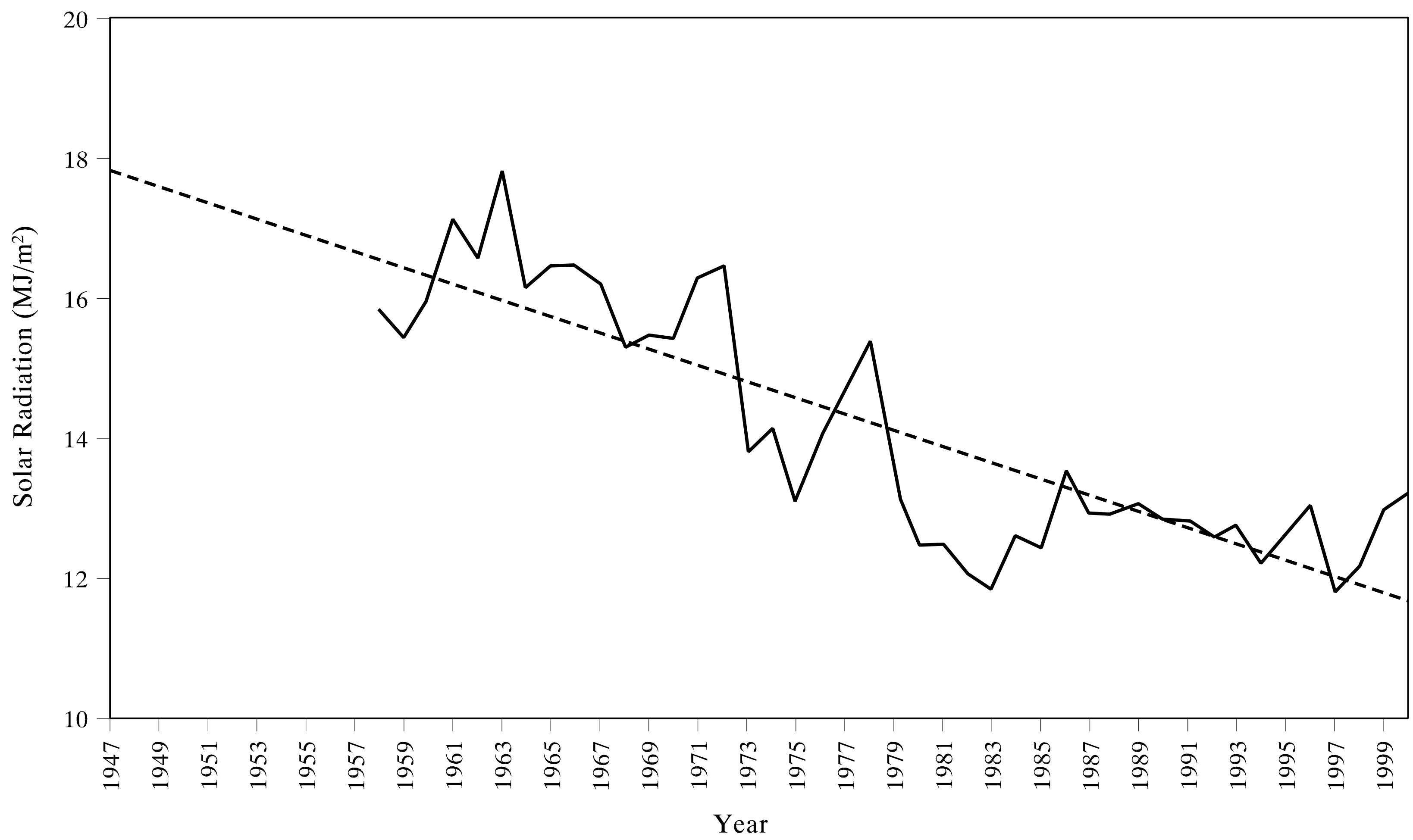

Figure 9 - Solar Radiation, Kings Park, 1957-2000